# REPORT DOCUMENTATION PAGE

*Form Approved OBM No. 0704-0188*



| 1. AGENCY USE ONLY *(Leave blank)* | 2. REPORT DATE | 3. REPORT TYPE AND DATES COVERED |
|---|---|---|
| | January 1999 | Proceedings |

**4. TITLE AND SUBTITLE**

Water Mass Distribution on the Shelf and Shelf-Break Upwelling in the Southeast Brazil Bight

**5. FUNDING NUMBERS**

*Job Order No.*

*Program Element No.*

*Project No.*

*Task No.*

*Accession No.*

**6. AUTHOR(S)**

Edmo J.D. Campos[1], Alberto R. Piola[2], and Jerry L. Miller

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**

Naval Research Laboratory
Oceanography Division
Stennis Space Center, MS 39529-5004

**8. PERFORMING ORGANIZATION REPORT NUMBER**

NRL/PP/7332--99-0013

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**

Universidade de Sao Paulo
Brazil

InterAmerican Institute for Global Change Research

**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

**11. SUPPLEMENTARY NOTES**

10th Symposium on Global Change Studies, 10-15 January 1999, Dallas, TX

[1]Instituto Oceanografico, Universidade de Sao Paulo, Brazil

[2]Departamento Oceanografia, Servicio de Hidrografia Naval, Buenos Aires, Argentina

**12a. DISTRIBUTION/AVAILABILITY STATEMENT**

Approved for public release; distribution is unlimited.

**12b. DISTRIBUTION CODE**

**13. ABSTRACT** *(Maximum 200 words)*

The region along the Brazilian coast situated between 22° S and 28° S is usually referred in the literature as the Southeast Brazil Bight (SBB). In the central part of the SBB (23° - 26° S), the continental shelf is relatively wide, with width reaching over 240 km in the region offshore of Santos. On the shelf, both the dynamics and the water mass structure are strongly influenced by intrustions of the BC, caused by the frequent meandering of that western boundary current. During the austral Summer, mostly due to the prevailing northeasterly winds, the water column is usually well stratified. The occurrence of intense coastal upwelling is frequently observed, especially in the region around Cabo Frio (22° S), and Ilha de Sao Sebastiao (24°). Campos *et al.*, suggested that the combination of this wind driven upwelling induced by BC cyclonic meanders constitute a mechanism responsible for pumping up oxygen and nutrient-rich SACW to the euphotic zones in the inner parts of the continental shelf. Incidentally, these shallower regions between 23° and 27° S are the most important spawning regions for the Brazilian Sardine *Sardinella Aurita.*

In this paper we discuss the water mass characteristics of the SBB continental shelf, based on AVHRR and hydrographic data collected during quasi-synoptic hydrographic cruises in the SBB during the Summer and Winter of 1993, and the Summer of 1994. The data set is described in Section 2. In Section 3 we discuss the surface temperature and salinity distributions. The three-dimensional water mass structure and time-variability are discussed in Section 4. In Section 5 we discuss the results and draw some conclusions.

**14. SUBJECT TERMS**

SBB (Southeast Brazil Bight), coastal upwelling, western boundary currents, cyclonic eddies, phytoplankton growth, East China Sea, and COROAS Experiment

**15. NUMBER OF PAGES**

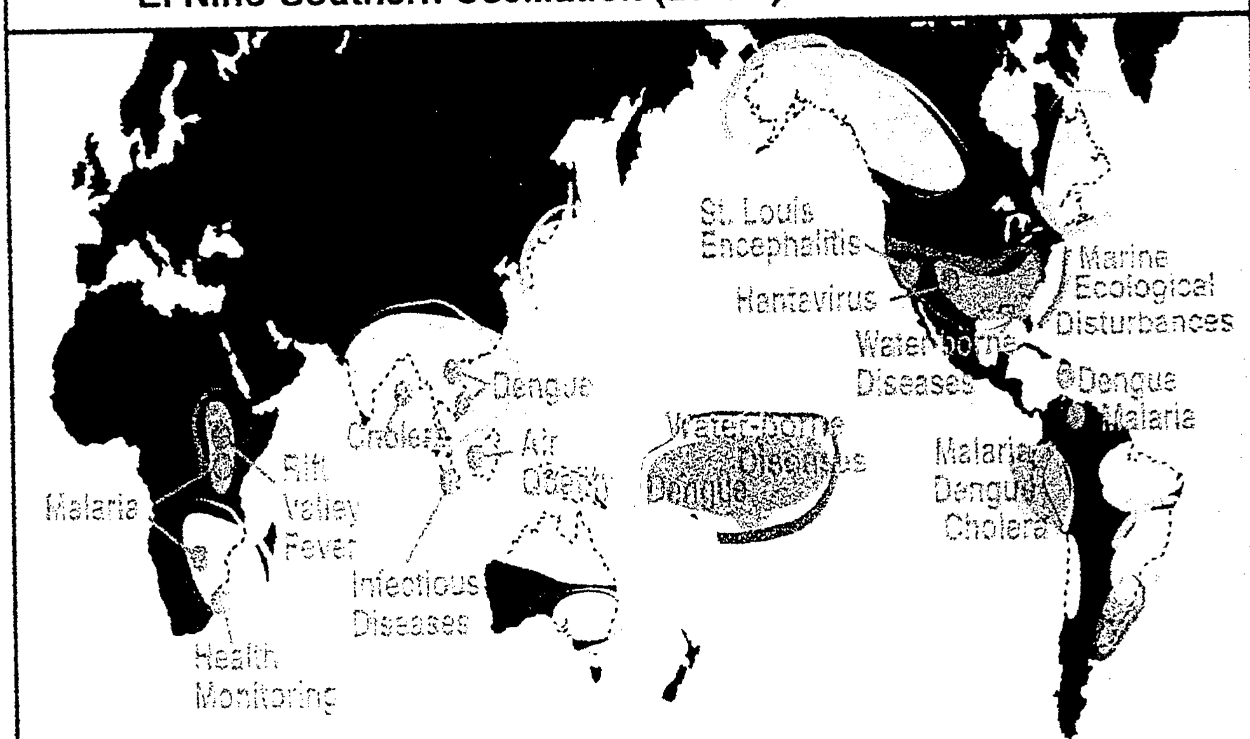
7

**16. PRICE CODE**

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| Unclassified | Unclassified | Unclassified | SAR |

# The ENSO Experiment
## Research Activities

**Exploring the Linkages between the El Niño-Southern Oscillation (ENSO) and Human Health**




**Generalized El Niño-Southern Oscillation (ENSO) Impacts**

= DRY
= WET
= WARM
= DRY & WARM
= WET & WARM
= WET & COOL

# 10TH SYMPOSIUM ON GLOBAL CHANGE STUDIES

**10-15 JANUARY 1999** **DALLAS, TEXAS**

**SPONSORED BY**
AMERICAN METEOROLOGICAL SOCIETY

*Front Cover.* The ENSO Experiment: An interdisciplinary research effort to study the relationship between the El Niño/Southern Oscillation and human health. This exploratory research activity is designed to draw together experts from various disciplines concerned with the influence of climate on human health. Research under this project builds on existing activities and involves a wide range of international academic, government and private sector partners. The ENSO Experiment is coordinated by the United States National Oceanic and Atmospheric Administration Office of Global Programs with additional funding and support provided by the Environmental Protection Agency, National Aeronautics and Space Administration, Centers for Disease Control and Prevention, United States Geological Survey, Agency for International Development, and the National Institutes for Allergy and Infectious Disease. For more details see paper 2C.3, "The ENSO Experiment: Using Climate Forecast Information to Provide Early Warning of Public Health Threats." Base map adapted from C. F. Ropelewski and M.S. Halpert, Global and Regional Scale Precipitation Patterns Associated with the El Nino/Southern Oscillation., August 1987, Monthly Weather Review, Vol. 115, pp. 1605-1626 and C. F. Ropelewski 1998, personal communication.





AMERICAN METEOROLOGICAL SOCIETY
45 BEACON STREET, BOSTON, MASSACHUSETTS USA 02108-3693

## TABLE OF CONTENTS

### 10TH SYMPOSIUM ON GLOBAL CHANGE STUDIES



* Manuscript not Available

5B.10

# WATER MASS DISTRIBUTION ON THE SHELF AND SHELF-BREAK UPWELLING IN THE SOUTHEAST BRAZIL BIGHT

Edmo J. D. Campos*
Instituto Oceanografico, Universidade de Sao Paulo, Brazil
Alberto R. Piola
Departamento Oceanografia, Servicio de Hidrografia Naval, Buenos Aires, Argentina
Jerry L. Miller
Naval Research Laboratory, Stennis Space Center, MS 39529, U.S.A.

## 1. INTRODUCTION

Upwelling associated with meandering of western boundary currents has been described by several authors in the recent years. Nakano, (1977) reports observations of upwelling associated with the Kuroshio along the shelf edge in the East China Sea; Fukasawa and Nagata (1978) describe extensive upwelling south of the Kyushu Island, where the Kuroshio Flows over a seamount; Pingree *et al.* (1979), in a study relating phytoplankton growth and cyclonic eddies, showed that extensive upwelling generated by these western boundary current are associated with the increase of clorophyll; Takahashi *et al.* (1981) describe shelf break upwelling associated with vortex motion off Oshima Island, in Japan; Osgood *et al* (1987) not only describe the vortex induced upwelling in the Gulf Stream, but also compute the associated vertical velocities; Atkinson *et al.* (1987), based on the results of extensive observations of the summer upwelling on the southeastern continental shelf of the U.S.A., conclude that a western boundary current, such as the Gulf Stream, can dominate the physics, chemistry, and biology of adjacent shelf waters. Atkinson *et al.* (1987) also suggest that the same should be true in similar shelf areas at the same or lower latitudes throughout the world. In their conclusion they point out that the Brazil Coast and the East China Sea would be particularly favorable for such processes to occur.

The region along the Brazilian coast situated between 22° S and 28o S is usually referred in the literature as the Southeast Brazil Bight (SBB) (Fig. 1). In the central part of the SBB (23 - 26° S), the continental shelf is relatively wide, with width reaching over 240 km in the region offshore of Santos. On the shelf, both the dynamics and the water mass structure are strongly influenced by intrusions of the BC, caused by the frequent meandering of that western boundary current (Miranda and Castro Filho, 1979; Campos *et al.*, 1995). During the austral Summer, mostly due to the prevailing northeasterly winds, the water column is usually well stratified. The occurrence of intense coastal upwelling is frequently observed, especially in the region around Cabo Frio (22° S), and Ilha de Sao Sebastiao (24°). Campos *et al.,* (1995) suggested the the combination of this wind driven upwelling with the shelf break upwelling induced by BC cyclonic meanders constitute a mechanism responsible for pumping up oxygen- and nutrient-rich SACW to the euphotic zones in the inner parts of the continental shelf. Incidentally, these shallower regions between 23° and 27° S are the most important spawning regions for the Brazilian Sardine *Sardinella Aurita* (Bakun and Parrish, 1991; Matsuura, 1996).

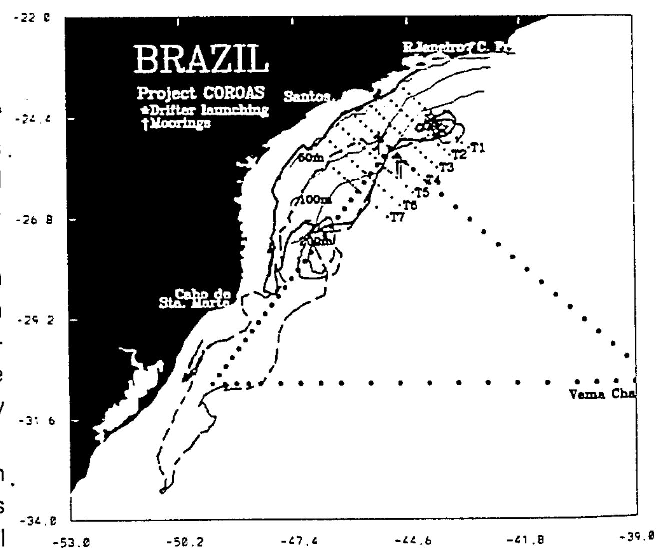



Figure 1: Map of Southeast Brazil Bight (SBB) showing the region of the COROAS Experiment. The smaller dots indicate the meso-scale array of hydrographic stations, formed by 7 transects (T1-T7). The bigger dots mark the position of the large-scale hydrographic stations. Also shown are the sites of current meter moorings and drifter deployments, and the trajectories of some of the drifters.

While the coastal upwelling in the SBB weakens considerably during the austral Winter, there are reasons to believe that the meander-induced shelf break upwelling is a mechanism that can occur in any season. Evidences

* *Corresponding author address:* Departamento de Oceanografia F˜sica, Instituto Oceanografico, Universidade de Sao Paulo, 05508-900 S ao Paulo, SP, Brazil; e-mail: edmo@usp.br

of this process were observed during three quasi-synoptic oceanographic cruises carried out in the SBB in Jan/93, Jul/93 and Jan/94, as part of Project COROAS. The frequent occurrence of this type of upwelling certainly acts positively in the maintainance of the primary production over the continental shelf throughout the year. In spite of the year-round occurrence of shelf break upwelling pumping SACW onto the outer regions of the shelf, the availability of that water to the inner shelf or to the surface layers is greatly reduced in the wintertime. During the winter, due to the weakening of the northeasterly winds, the coastal upwelling is much less frequent than during the summer. Also, there are times when anomalously cold (T < 16° C at 28o S) and low salinity water (S < 32 at 28° S) water is observed in the entire water column in the inner shelf (inshore of the 100 m isobath). During these events, the SACW is completely confined to the outer regions of the continental shelf. This represents an interannual variability that has profound impacts in the primary productivity of the region.

In this paper we discuss the water mass characteristics of the SBB continental shelf, based on AVHRR and hydrographic data collect during quasi-synoptic hydrographic cruises in the SBB during the Summer and Winter of 1993, and the Summer of 1994. The data set is described in Section 2. In Section 3 we discuss the surface temperature and salinity distributions. The three-dimensional water mass structure and time-variability are discussed in Section 4. In Section 5 we discuss the results and draw some conclusions.

## 2. THE DATA SET

The hydrographic data used for the present article were collected during the COROAS Experiment, a Brazilian contribution to WOCE. COROAS included three oceanographic cruises in the central part of the SBB, as indicated in Fig. 1. These quasi-synoptic hydrographic surveys were conducted during the austral Summer (Jan/14-Feb/2) and Winter (Jul/15-31) of 1993, and the Summer (Jan/15-31) of 1994. The surveys encompassed most of the continental shelf and extended through the Brazil Current into the subtropical gyre. In each cruise a number of about 100 stations were occupied for collection of CTD and nutrient data. The CTD casts covered the whole water column, from the surface to 2500 m depth. During each of those cruises 5 WOCE-type drifters were launched in the sites indicated in Fig. 1. AVHRR were continuously recorded for the analysis of the sea surface temperature.

## 3. SURFACE TEMPERATURE AND SALINITY

AVHRR and in situ COROAS observations of the sea surface temperature during the Winter 1993 show the presence of tongue of low salinity and low temperature water in the central region of the SBB (Campos *et al.*, 1996a,b). For illustration, Figure 2 show the horizontal distribution of temperature at 10 m depth. Analyses of AVHRR images processed at the Univ. of Miami for a larger area suggest that the origin of this cold water might be located far to the south (Campos, 1996b). Campos *et al.* (1996a,b) described the trajectories of three surface drifters deployed in the Brazil Current near 24° S in January 1993 (see Fig. 1). After drifting southward for a period of 2 to 4 months, the three drifters moved onshore (at different time and locations) and described an elongated cyclonic loop to return northward over the shelf and reach, in July, latitudes close to that of deployment. Sea surface temperature from the drifters was close 25° C along the southward path over the Brazil Current, and 20° S over the shelf. An additional drifter deployed at the Brazil Current in late April 1993 near 30° S also drifted onshore and followed a similar path and temperature trend, suggesting that the northward recirculation was indeed a large scale feature at the time.

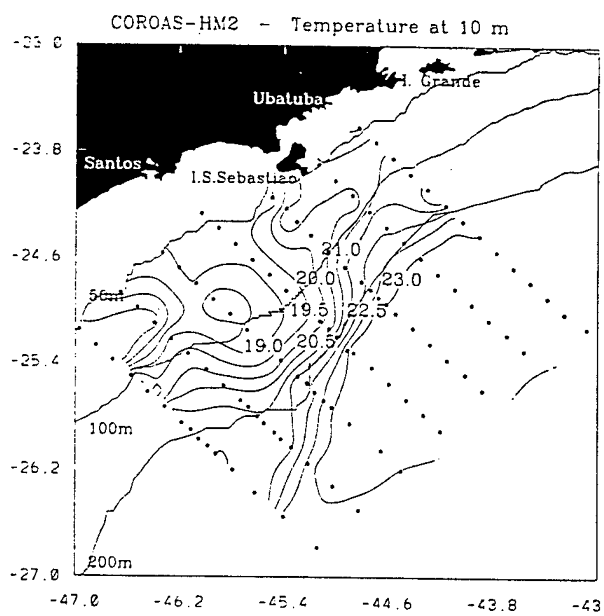



Figure 2: Temperature distribution at 10 m depth based on CTD data collected during the during Winter/93 COROAS cruise. It shows a tongue of low temperature water entering the surveyed area from the southwestern corner.

This northward penetration of water from the northern Argentine/Uruguayan shelf regions is in fact a seasonal a seasonal phenomenon, observed during the winter time. However, this penetration usually does not reach latitudes

lower than 28° S. The outbreak of this water mass into the SBB, in latitudes as low as 23° S, is apparently an interannual feature which has been, among other things, associated with recruitment failure of the *Sardinella Aurita* [*Matsuura, 1996*]. In a study of the water masses off eastern South America, from 20° to 40° S, *Piola et al. [1998]* suggest that this tongue of low salinity and low temperature water observed in the SBB continental shelf is possibly related to the northward penetration of the winter low salinity water from the Plata and Patos outflow.

## 4. SHELF BREAK UPWELLING AND THE SHELF WATER MASS STRUCTURE

As shown in Figure 3, the T-S characteristics indicate the presence of pure South Atlantic Central Water (6° < T < 18.5° C; 34.5 < S < 36.0) over a large area of the continental shelf. Since this water mass is usually found in depths greater than 200 m, in the slope region, there might be a mechanism responsible for pumping that water onto the shelf. *Campos et al.* [1995] suggest that during the summer this mechanism could be a positive combination of shelf-break upwelling, induced by cyclonic meanders of the Brazil Current, and wind-driven upwelling near the coast. During the winter, when coastal upwelling is diminished, practically only the meander induced upwelling would contribute, with the SACW being mostly confined to the outer shelf.

The COROAS data seem to confirm these two possible scenarios, as shown in Figure 4. It represents the vertical distribution of temperature along the fifth (T5) transect of the COROAS meso-scale array (Fig. 1), for the summer of 1993 (upper) and winter of 1993 (lower). Incidentally, in both opportunities the leading part of a cyclonic meander were crossing the T5 transect, as can be seen by the geometry of the isotherms. In both situations the SACW was found climbing the continental slope onto the shelf (see, for instance, the 16° C isotherm). However, only in the summer the SACW reached the shallower regions, certainly due to the additional action of the wind driven Ekman pumping.

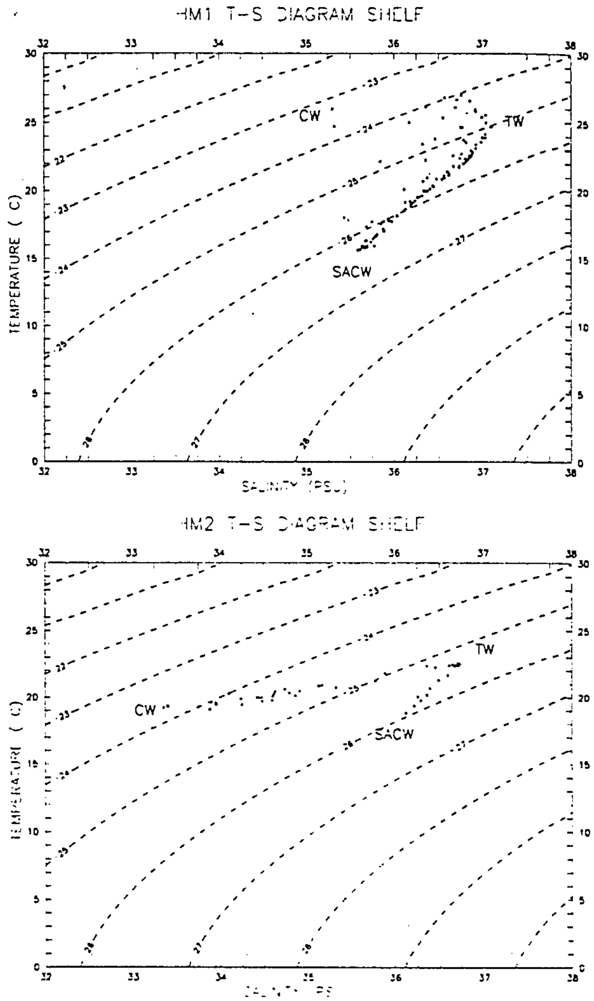



Figure 3: Temperature-Salinity diagrams for the shelf area in Summer/93 (upper panel) and Winter/93 (lower panel). In both cases is is clear the presence of the SACW in a relatively large number of stations.

## 5. DISCUSSION AND CONCLUSIONS

The COROAS data seem to confirm the hypothesis that in the SBB the Subtropical Shelf Water is originated by dilution of SACW, both by nearby continental runoff and by waters advected from southern latitudes. The data also seem to confirm that the mechanism responsible for pumping the SACC onto the shelf is mainly due to meander induced shelf break upwelling, during the winter, and a combination of shelf-break and wind-driven upwelling in the summertime, as illustrated by Fig. 5. In this process SACW is initially pumped up and deposited on the shelf by divergence in the leading part of the meander. During the summer, when the wind is, on average, upwelling-favorable, the the offshore Ekman transport would account for the coastal upwelling. During the winter this wind-driven process is weakened and, although SACW can still be found in the outer shelf, much less of it reaches the surface layers. In some winters, this situation is even worsened by the presence of the low-density water originated in the south, as observed in the winter of 1993.

Results of eddy-resolving (resolution 1/12 of degree) simulations with the Miami Isopycnic model (MICOM) in the SBB, conducted by the first author, are reproducing quite well the shelf break upwelling. These results show that the upward velocity associated with the divergence near the leading edge of the cyclonic meanders are comparable

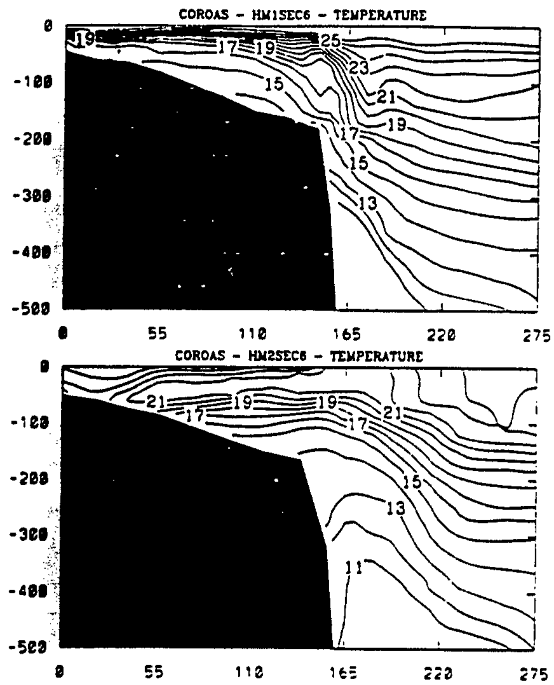



Figure 4: Vertical sections of temperature showing the pumping of SACW onto the shelf. During summer (upper panel) the SACW reaches the shallower regions due to the combined effect of wind-driven and shelf break upwelling.

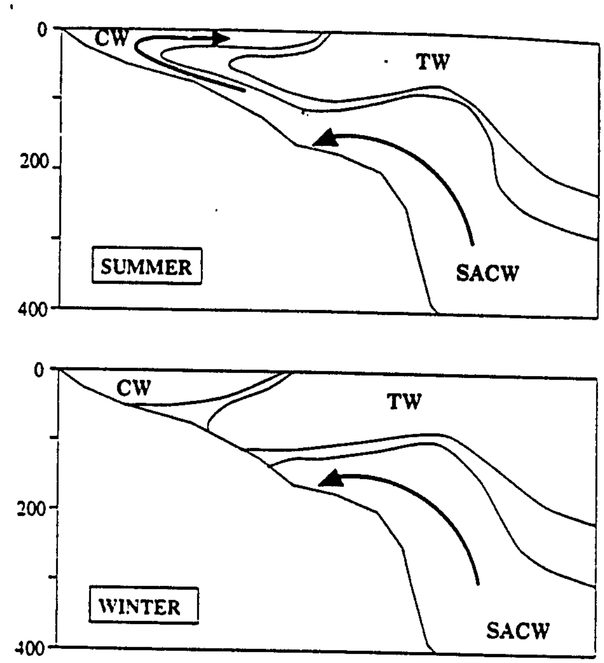



Figure 5: Schematic of the combination Shelf break and wind-driven upwelling for summer (upper panel) and winter (lower panel).

with the results obtained in the literature.

**Acknowledgements.** Project COROAS was funded by FAPESP (grant 91/0542-7) and CNPq (grant 40.3007/91.7). This work is part of the SACC and SAMC activities. supported by FAPESP and by the Inter American Institute for Global Change Research (IAI).

## References

Atkinson, L.P, T.N. Lee, J.O. Blanton, and G.-A. Paffenhoffer, 1987: Summer Upwelling on the Southeastern Continental Shelf of the U.S.A. During 1981. *Prog. Oceanogr.*. 19, 231-266.

Bakun, A. and R.H. Parrish, 1991: Comparative studies of coastal pelagic fish reproductive habitats: the anchovy (*Engraulis anchoita*) of the Southwestern Atlantic. *ICES J. Mar. Sci.*, 48, 343-361.

Campos, E.J.D., J.E. Goncalves & Y. Ikeda, 1995: Water Mass Characteristics and Geostrophic Circulation in the South Brazil Bight - Summer of 1991. *J. Geophys. Res.*, 100(9), 18537-18550.

Campos, E.J.D., Y. Ikeda, B.M. Castro Fo., S.A. Gaeta, J.A. Lorenzzetti & M.R. Stevenson, 1996a: Experiment Studies Circulation in the Western South Atlantic. *EOS, Transactions, Am. Geophys. Union, 77* (27) 253,259.

Campos, E.J.D., J.A. Lorenzzetti, M.R. Stevenson, J.L. Stech, & R.B. de Souza, 1996b: Penetration of Waters from the Brazil-Malvinas Confluence Region Along the South American Continental Shelf up to 23°S. *Acad. Bras. Ciências* 68(1), 49-58.

Fukasawa, M. and Y. Nagata, 1978: Detailed oceanographic structure in the vicinity of the Shoal Kokoshosone, *Jour. Oceanogr. Soc. of Japan* 34, 41-49.

Miranda, L. B., and B. M. Castro Fo., 1979: Condicoes de Movimento Geostrofico das Aguas Adjacentes a Cabo Frio (RJ). *Bolm. Inst. Oceanogr.*, 28(2), 79-93, 1979.

Matsuura, Y., 1996: Probable Causes of Recruitment Failure of the Brazilian Sardine Population in the 1974/75 Spawning Season. *South African J. Mar. Sc.*, *17*, 29-35.

Nakano, T., 1977: Oceanic variability in relation to fisheries in the East China Sea and the Yellow Sea. *Jour. of the Faculty of Marine Sci. and Techn.* Tokai Univ., Special number, November, pp. 199-367.

Pingree, R.D., P.M. Holligan and G.T. Mardell, 1979: Phytoplankton growth and cyclonic eddies. *Nature*, 278, 245-247.

Piola, A. R., E.J.D. Campos, O. O. Moller Jr., M. Charo and C. Martinez, 1998: Continental shelf water masses off Eastern South America - 20° to 40° S. *Proceedings of the 79th AMS Ann. Meeting - 10th Symp. on Global Change* (paper P1.2).

Takahashi, M., Y. Yasuoka, M. Watanabe, T. Miyazaki and S. Ichimura, 1981: Local Upwelling Associated with Vortex Motion off Oshima Island, Japan. *Coastal Upwelling - Coastal and Estuarine Sciences 1*, F. A. Richards, Ed., Am. Geophys. Union, 119-124.